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Visual Response to Decremental Luminance Ramp Estimated by the Masking Technique with the Decremental Probe

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In our previous studies (Takiura, 2002, 2003), visual responses to the luminance decrement with temporally ramped profile were estimated psychophysically by the technique of the masking of light with the incremental luminance probe. The graph in which the probe thresholds are plotted in logarithmic form against the probe delay for the onset of the mask is called masking curve, and is believed to be a psychophysical copy of the temporal course of the off-response at the relatively peripheral stages in the visual system. We have found that with shorter luminance transition times the overshoot appeared on the masking curve just after the onset of the ramp regardless of the luminance transition time. The overshoot disappeared with longer luminance transition time. The amplitude of the retinal responses of the cat and the trout to the decremental luminance ramp, however, was reported reaching their maxima at and just after the end of the ramp. In the present experiment, we obtained the masking curve for the decremental luminance ramp with the decremental luminance probe to investigate the peak delays of the psychophysical off-response under the condition that both the mask and probe were the same luminance polarity. The masking curve reached its peaks at the start of, during, and at the end of the ramp, which were quite different from those obtained with the incremental probe. This result was interpreted to show that the way of detection and estimation of the human visual system to the temporal darkening differs from that of the cat and the fish.

Key words: decay times, off-responses, masking.

Introduction

In most studies on the masking of light, the pulse of light has been employed as a probe to assess psychophysically the time course of the early light or dark adaptation or of the transient visual response evoked by the temporal luminance change in the adapting background usually called a mask (e.g. Baker, Doran & Miller, 1959; Boynton & Siegfried, 1962; He & MacLeod, 2000; Hood, Graham, von Wiegand & Chase, 1997; Snippe, Poot & van Hateren, 2000). The masking curve is a graph, in which the probe thresholds are plotted in logarithmic form as a function of the temporal asynchrony with the mask onset. The masking curve has been thought to be the psychophysical record of the transient response at the relatively peripheral stage, or at the retina, in the visual system (Hood, 1998).

In most of the studies obtaining the masking curve, only the mask with a sharp luminance change has been tested, because it is believed that the magnitude of the visual response to the

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stimulus of the same luminance is maximal when its temporal edge is abrupt. In a different view, however, the temporal waveform of the stimulus, or the temporal luminance gradient of the stimulus, can be regarded as an important variable for the temporal vision.

Using the incremental light pulse as a probe, Matsumura (1976, 1977) and Takiura (2002, 2003) obtained the masking curves for the mask with gradual luminance change. They showed that the probe threshold rose abruptly at or around the onset of the mask to form the overshoot of the masking curve. That is, the peak height of the masking curve decreased and its temporal course slowed down with the decrease of the temporal luminance gradient of the mask. This dependency of the shape of the curve on the temporal luminance gradient of the mask was larger for the incremental mask than for the decremental one.

With the incremental mask, the probe threshold should be determined by the interaction between the on-response evoked by the onset of the mask and that initiated by the probe, which occurs in the ON channel in the visual system. So, it seems to be appropriate to think of the form of the masking curve obtained with the combination of the incremental mask with the incremental probe as a psychophysical record of the transient on-response in the ON channel in the human visual system, regardless of some nonlinear relation between the amplitude of the neuronal response and the psychophysically-estimated one reported in the study of Limulus vision (Felsten & Wasserman, 1979). With the decremental mask, the threshold of the probe must be determined as the result of the interaction between the transient off-response evoked by the onset of the decremental luminance mask in the OFF channel and the transient on-response for the probe in the ON channel. Such a response interaction may be made in a more complex manner than that between the mask and the probe of the same luminance polarity, so the masking curve for the decremental mask might not be a good approximation of the time course of the transient response in the OFF channel.

In our previous experiments and in the Matsumura's ones, the peak of the overshoot of the masking curve for the decremental mask with temporally ramped profile was always appeared just after the start of the mask. It was located at the delay of 50 ms at most with the ramp of the duration as long as 250 to 360 ms. In their study on the human VECP, Clynes, Kohn and Lifshitz (1964) found that in the visual cortex the amplitude of the off-response reached its maximum in the middle of the decremental luminance ramp of 500 ms in duration, which is not comparable with the masking data. In the neurophysiological studies of the cat and the fish (rainbow trout), the peak position of the off-response of the retinal neuron was located at the last part of or just after the linear or exponential luminance ramp lasting 10 to 10000 ms (Bornschein, 1962; Enroth-Cugell & Jones, 1963; Penzlin & Hopp, 1985). This is not also in accord with the psychophysical finding with masking curve, though some units of cat retinal ganglion cells showed the response peak during the stimulus ramp phase of 50 to 1500 ms in duration (Enroth-Cugell & Jones, 1963). As contrast with this discrepancy in the temporal location of the peak relative to the luminance ramp between the retinal neuronal response and the psychophysically-estimated one, studies on the response to the incremental luminance ramp are in good agreement between the retinal neurophysiology and psychophysics in the point of the peak position of the response (See Takiura, 2002, for review of this literature). That is, in both kinds of study the response peak appeared just after the onset of the incremental luminance ramp. These facts make us speculate that the temporal response characteristics of the OFF channel largely differ between the human and other kinds of animal as the cat and the fish, whereas those of the ON channel are similar among them. It also be possible, however, to attribute the cause of discrepancy between the neurophysiological data and the behavioral ones with the decremental luminance ramp to the difference in luminance polarity between the mask and the probe used in the masking experiment with human subjects.

In the present experiment, masking curves were obtained for the decremental luminance ramp with a decremental probe to judge which of the two possibilities mentioned above on the reason for the discrepancy in the peak position between the neurophysiological and psychophysical off-response is more valid. With this combination of the mask and probe, the interaction between the responses to these stimuli should occur only in the OFF pathway. So one can expect the time course of the response of the OFF channel to be copied as a psychophysical masking curve in a more proper way under this simulation condition than under the condition with the mask and probe of opposite luminance polarity.

Methods

Subjects

The author and two male undergraduate students in psychology participated in the experiment. They had normal or corrected-to-normal visual acuity. Data from the two eyes of subject TT were collected separately and were identified by TT-R and TT-L after Buck (1985a, 1985b). For other subjects only the right eye was used.

Apparatus and stimuli

A single channel Maxwellian-view optical system was used for stimulus presentation. The light source was a green light-emitting diode (Sharp, LT9560E, 565 in peak wavelength and 12 nm in half bandwidth). Stimulus observation was done with monocular viewing. No artificial pupil was used.

The preadapting field of 1.43° in diameter and of 309.1 td in retinal illuminance (98.4 cd/m^2 in luminance) consisted of a train of light pulses, each of which was of constant duration of 3 μs and 20 kHz in frequency. The adapting background of 1000 ms in duration, the decremental luminance mask, and the decremental probe of 16 ms in duration were also 1.43° in diameter, and were presented by pulse density modulation using the voltage-to-frequency converter (NF Corporation, FC-113). In most of the experiments obtaining the masking curve, a probe is used that is far smaller in diameter than the mask. Such a mask-probe combination may be employed because of the easiness of the subject's judgment at the time of the probe detection due to the availability for spatial contrast between the probe and the surrounding mask area as a detection cue. Kitterle and Leguire (1975, 1980), however, reported that the shape of the masking curve for abrupt luminance decrement did not essentially changed when the probe and the mask were spatially coextensive, where only a purely temporal cue can be used for probe detection, though the magnitude of the threshold elevation was larger and thus the decline of the masking curve after the peak was also larger than those with different size between the probe and the mask.

The optical system was interfaced to a personal computer (NEC, PC-9801US). The voltage waveform fed into the input of the voltage-to-frequency converter was generated by the laboratory-made digital-to-analog converter consisted of the ladder-resistors. The retinal illuminance of the mask was 58.8 td (18.7 cd/m^2 in luminance). The ramp period of the mask, that is, the ramp duration, was 0, 125, 250, or 500 ms in duration. Since the observation was made with foveal view, the stimulus dimension corresponds to the retinal area as large as, or slightly larger than, the rod-free area (Curcio, Sloan, Kalina & Hendrickson, 1990). No surround was presented. Frumkes, Lange, Denny and Beczkowska (1992) showed psychophysically that sensitivity of cones to the rapid-off sawtooth flicker considerably decreased when the rod within the area surrounding the foveal stimulus dark adapted. In the present stimulation condition, the rods in the outside of the stimulus would light adapt, so that the effect of the suppressive rod-cone interaction upon the result would be very small, if any, by the entoptic light scatter from the preadapting field with higher illuminance (Krauskopf, 1962; Vos, Walraven & van Meeteren, 1976).

Procedure

Subjects were seated in a light-proof, ventilated room and stabilized the position of their heads by a head holder and a chin rest with the biting board arrangement. Before the measurements, they dark-adapted for 5 min first, and then light-adapted to the steady preadapting background for 5 min.

One trial was conducted as follows. The preadapting field was always presented. After the presentation of the warning tone of 100 ms, the preadapting field was increased in illuminance by 58.8 td for 2000 ms, resulting in the 367.9 td of adapting level. Then the ramp-like decremental mask was presented, followed by the return to the illuminance level of the preadapting field of 309.1 td for 1000 ms. Next, the illuminance increment of 58.8 td was added again for 2000 ms, which was followed by presentation of the combination of the mask with the probe. Probe threshold was obtained by the modified method of limits. The task of the subject was to detect the probe superimposed upon the second mask or upon the following preadapting field. Results obtained by this method were quite similar to those obtained in the pilot experiment using the staircase method with 2AFC. Test was also done for the two subjects with the incremental probe for comparison.

In the experimental session, the test was done with only one ramp duration. Within a session, the temporal delay of the probe was tested in a randomized order. The session for one ramp duration was repeated three times on a separate day. Sessions with different ramp duration were randomly intermixed. In each session, three thresholds were collected consecutively at each delay interval.

Results

The results are presented in Figure 1. In each panel, each point of the masking curve is based

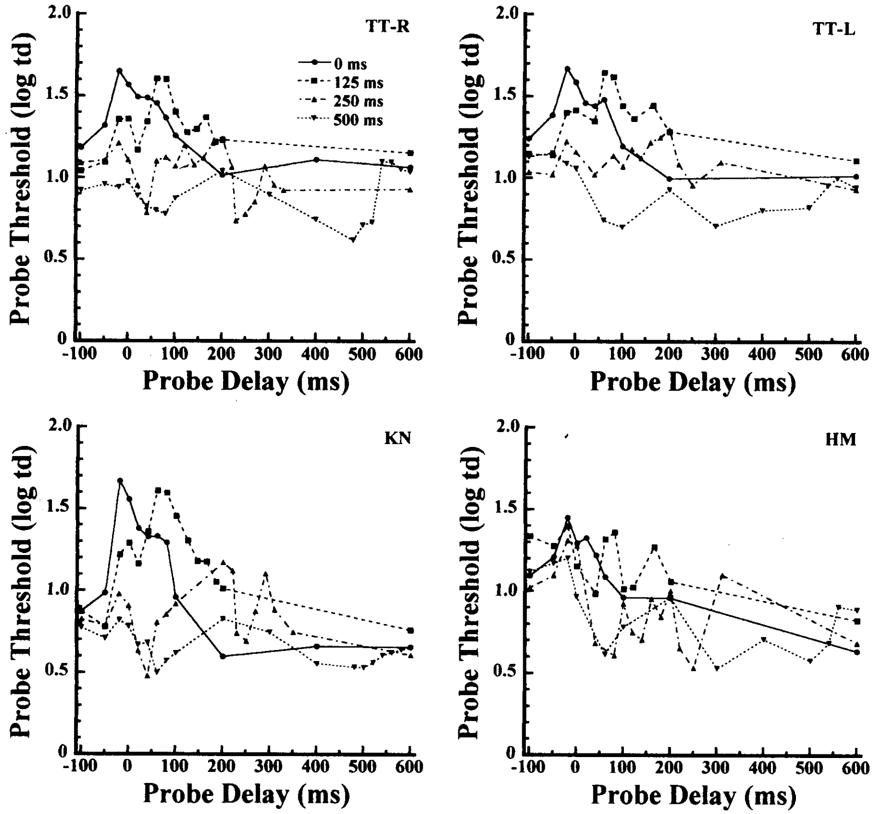

Figure 1. Masking curves for the decremental luminance mask with the decremental probe. The parameter of the curve is the ramp duration of the mask.

on nine data. In this figure, the log threshold illuminance of the probe is plotted as a function of the probe delay in reference to the temporal point at which the mask was presented. Negative values of the delay indicate that the probe was presented before the presence of the mask. The parameter of the graph is the ramp duration of the mask.

With instantaneous luminance change of the mask, a sharp peak of the threshold overshoot was located at -20-0 ms of the probe delay. With the ramp duration of the mask was increased to 125 ms, a sharp peak appeared in the masking curve at about 60-80 ms, whose magnitude was almost the same as that with the ramp duration of 0 ms. In addition, a small but distinct peaks or shoulders appeared at or just before the onset of and after the mask. When the ramp period of the mask was increased to 250ms and to 500 ms, the peaks also appeared at the start of or just before, during, and after the ramp. During the ramp, the curve seems to reach its peak at about 200 ms delay, though the probe threshold was obtained only with 200 ms delay between 100 ms and 300 ms delay times for the 500 ms ramp. The peak appeared with the probe delay of 50 ms after the ramp offset. The peak magnitude of the curve decreased with the increase of the ramp duration. The trough before and after the second peak was relatively sharp and rather large in

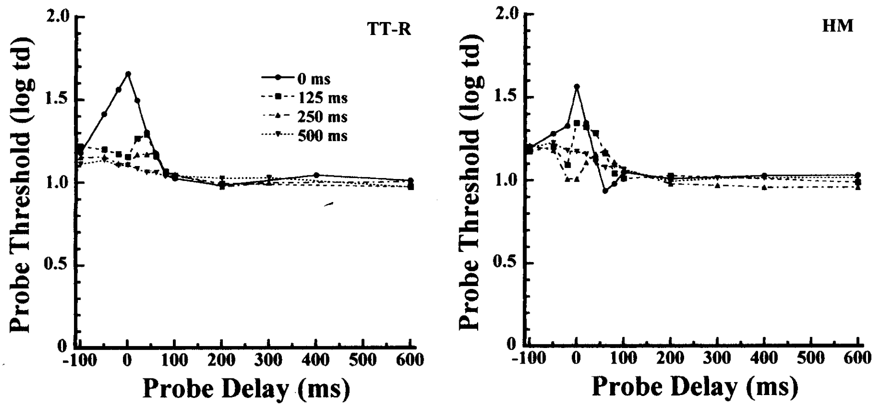

Figure 2. Masking curves for the decremental luminance mask with the incremental probe. Presentation is as in Figure 1.

magnitude.

The masking curves obtained with the incremental probe are shown in Figure 2. Presentation is as in Figure 1.

The masking curves obtained with the decremental probe in the present experiment were quite different from those obtained with the incremental probe in their shape. First, the magnitude of the threshold change was far larger for the condition with the decremental probe than for that with the incremental one. Second, with incremental probe, the masking curve had only a single peak, whereas with decremental probe, three peaks appeared in the curve with prolonged ramp. For the masking curve with the probe of opposite luminance polarity and with the same ramp duration, the peak delay was not in agreement with each other except the case with instantaneous illuminance change where the delay of the peak with the incremental probe was similar to that of the first peak with the decremental probe. Third, the magnitude of the peak tended to be larger with the decremental probe, especially for the second peak, than that with the incremental probe. And fourth, although the peak of the masking curve with the incremental probe completely disappeared for the decremental ramp of 500 ms in duration, the peaks were clearly noticed in the masking curve with the decremental probe.

Discussion

The result of the present experiment using the decremental light pulse as a probe shows that the peak of the human visual transient off-response at the retina recorded by the psychophysical method to the stimulus with decremental temporal luminance gradient is not located only at the start of the luminance decrease as the case with incremental luminance probe (Matsumura, 1976, 1977; Takiura, 2002, 2003, and Figure 2 in the present report) but located at or just before the start of, during, and after the end of the ramp period. The sharp troughs before and after the second peak may be the reflection of the response of the inhibitory process.

The masking curve for the decremental luminance mask with the decremental probe seems to be a better psychophysical record of the time course of the response of the OFF channel than that with incremental probe, because the intra-channel interaction of the response between the decremental mask and the decremental probe will be made in a simpler way than the inter-channel response interaction between the decremental mask and the incremental probe, that is, the response interaction between the OFF channel and the ON channel, as the reciprocal lateral inhibition (Singer & Phillips, 1974). The fact that the masking curve was quite different in shape between the conditions with opposite probe polarity strongly suggests that the masking curve with the combination of the decremental mask and the incremental probe is inappropriate to the psychophysical estimate of the response of the OFF channel.

The shape of the masking curve with the decremental probe also differs very much from the temporal course of the ERG for the ramped luminance decrement for the cat and the fish (Bornschein, 1962; Enroth-Cugell & Jones, 1963; Penzlin & Hopp, 1985). That is, the peaks of the curve were located at the start of, during, and after the luminance ramp for the former, while for the latter the photopic retinal response peak was noticed only at the last part of or just after the ramp-like luminous decrements. This fact suggests that the manner of estimating the gradual decrease in luminance is different between the man and other animals as the cat or the rainbow trout. This does not mean that the cat and the fish cannot perceive the gradual change in luminance. Only the transient part of the response to the supraliminal decremental luminance ramp may not necessarily make the contribution toward perceiving the gradual brightness change. The sustained component, the amplitude of which is changed with the slow luminance change, as well as the transient one may contribute to the way of the perception of the temporal brightness change, for the cat and the fish.

For the man, however, it seems that the gradual temporal luminous change is assessed on the basis of the peaks of the off-response reflected in the masking curve. The second peak may reflect the activity on which the temporal slope of the luminance decrement is estimated rather than that of the mechanism that acts only for detection on the luminance decrement. If the second peak is the appearance of the response of the mechanism only detecting luminance decrement, the responses reflected in the first and third peaks may not be necessary to be evoked and the decrement of the luminous energy necessary for the second peak to reach the peak may be constant. The decrement of the luminous energy of the mask before the appearance of the peak, however, was not constant but increased with ramp duration (about 3000 td $\times$ ms for 125 ms ramp, about 7000 td $\times$ ms for 250 ms ramp, and about 10000 td $\times$ ms for 500 ms ramp). The third threshold peak may correspond to the response peak on which detecting the end of the luminance change is based. The first peak may reflect the response detecting the start of the luminance decrease. But this idea cannot deny the possibility that the first peak of the masking curve was contaminated by the artifact of the contour effect or the strong lateral inhibition of the edges between the mask and the probe. In their studies on the visual sensitivity at the perifovea, Battersby and Wagman (1962, 1964) showed that the incremental threshold overshooted at the abrupt luminance decrement of the mask of the same diameter as the probe, though the threshold overshoots was not observed with the mask of the larger size. This fact suggests that the peak of the masking curve at or arround the start of the decremental mask does not necessarily reflect the activity of the neuron of the OFF channel but, in a certain condition, reflect the time course the interaction of the contours between the mask and the probe. If the first threshold peak reflected the off-responses of the OFF channel, which is believed to be the neurophysiological basis of the darkness sensation, it seems to have been delayed according as the ramp period of the mask increased, because the longer ramp period of the mask is, the longer time the detection of the luminance decrease will take.

Clynes, Kohn and Lifshitz (1964) reported that the off-response of the human VECP to the single rapid-on sawtooth of the luminance reached its maximum in the middle of the ramp phase of the sawtooth, which is comparable in part with our psychophysical data, that is, with the second peak of the masking curve. Since it is well established that the neuron in the visual cortex make no significant response to the stationary light spot, this suggests that the perception of the temporal luminance change of the unpatterned stimulus is given by the stimulus information transmitted in the visual system from the retina to the cortex by a relatively simple process. Unfortunately, however, the origin of the components of the human VECP for unpatterned light stimuli has not been completely specified (Allison, Matsumiya, Goff & Goff, 1977; Simon, Vaughan & Ritter, 1976).

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